To Study the effect of welding speed on mechanical properties of friction stir welding of Aluminum alloy

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Abstract: **The friction stir welding is recently developed solid state welding process which overcome the problem associated with fusion welding technology. The properties achieved by friction stir welding is better than that achieve by fusion welding technique. The aim of present study is to determine the effect of welding speed on mechanical properties of friction stir welding of Al alloy. AA 6101 T6 alloy was selected as base material and friction stir welding was carried out with hexagonal pin having concave shoulder. The thickness of the pin was 6mm having length of 5.7mm with 20mm shoulder diameter. The friction stir welding was carried out at two different welding speed i.e 78,120 mm/min at fixed tool rotation speed of 1070 rpm. The characterization was carried out in view to understanding of microstructure, hardness profile, tensile properties and the failure behavior of weldments. The result indicated the better contrast in each zone developed after friction stir welding. The weld samples which was prepared at 1070 rpm tool rotation speed and 120 mm/min welding speed posses maximum tensile strength of 123 Mpa. There was an average 57 % decrease in hardness in weld region compare to base metal**

Keywords: **FSW,** Microstructure analysis,Physical tests, Failure analysis

I.INTRODUCTION

The development of new materials and their practical application constitute a great challenge for manufacturing sector in many branches of industry. Numerous efforts concentrate on considerable reduction of manufacturing costs of various components and their assemblies. For this reason the noble concept are under continuous development. invented in 1991 by The welding Institute, friction stir welding is novel solid state joining process that is gaining the popularity in the manufacturing sector [1,2].

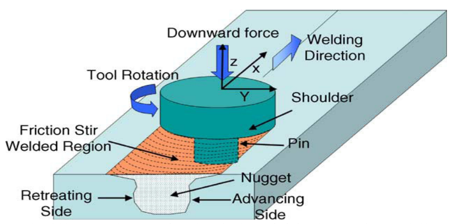

Figure 1 Schematic illustration of principle of friction stir welding[10]

FSW utilizes a rotating tool design to induce plastic flow in the base metals and to essentially “stir” them together. During the Friction stir welding ,the tool pin attached with shoulder ,is inserted between the abutting edges of plates to be joined. As the tool traversed along the joint line, the rotation of shoulder under the influence of an applied, fixed load heats the metal surrounding the joint and with the rotating action of the pin induces the metal from each work piece to flow together and form weld. The schematic figure representing the principle of friction stir welding is shown in the fig 1.

The microstructure resulting from the influence of plastic deformation and elevated temperature is generally a complex array of fine, recrystalized grains. The friction stir welding gives the best joining efficiency and mechanical properties with less negligible defect or defect free weld. Over the last fifteen years, numerous investigation have sought to characterize the principles of FSW and to model the microstructural development. The majority of these investigations pertains to heat treatable aluminum (2xxx,6xxx and 7xxx series) [3-6] and were simulated by the complex evolution of microstructure and thus properties in these alloys during FSW process. The current status of FSW research has been well summarized by Mishra and Ma [7]. Since no melting occurs during FSW, the process is performed at much lower temperatures than conventional welding techniques and circumvents many of the environmental and safety issues associated with these methods. FSW is considered to be the most significant development in metal joining in a decade and is a ‘green technology’ due to its energy efficiency, environment friendliness, and versatility.

Aluminum & Aluminum alloy are difficult to weld, requiring weld pool shielding gas & specialized heat sources, require the oxide layer to be stripped prior to or during the welding process. In addition, aluminum and its alloy are subject to voids & solidification cracking defects when they cool from a liquid state. Consequently, in order to manufacture large panels of aluminum & aluminum alloys extrusion has become choice of manufacturing. However, even extrusion has size limitations.

As compared to the conventional welding methods, FSW consumes considerably less energy. No cover gas or flux is used, thereby making the process environmentally friendly. The joining does not involve any use of filler metal and therefore any aluminum alloy can be joined without concern for the compatibility of composition, which is an issue in fusion welding. When desirable, dissimilar aluminum alloys and composites can also be joined with equal ease.

In contrast to the traditional friction welding, which is usually performed on small asymmetric parts that can be rotated and pushed against each other to form a joint, friction stir welding can be applied to various types of joints like butt joints, lap joints, T butt joints, and fillet joints. that the microstructure and resulting properties produced during FSW of aluminum alloys are dependent on several factors. The contributing factors include alloy composition, alloy temper, welding parameters, thickness of the welded plates as well as the shape and geometry of applied tools. These changes are exceptionably evident in age-hardenable alloys where severe plastic deformation accompanied by mixing of material as well as heating and cooling cycles alters the microstructure (and thus properties) in a significant manner.

The quality of friction stir welding depending on the geometry of tool pin & shoulder of tool the process parameters also affect the quality of weld i.e. tool rotation speed, traverse speed, tool tilt angle, D/d ratio where D indicates diameter of shoulder & d indicates diameter of tool pin, etc.

The aim of this present study is to determine the effect of welding speed on mechanical properties of Friction stir welding of Al alloy. For the present study AA6101 T6 age hardenable alloy was selected as basemetal. The friction stir welding was carried out with hexagonal pin with concave shoulder. The tool pin having 6 mm thickness and 5.7 mm pin length with 20 mm shoulder diameter. The friction stir welding was carried out at 1070 rpm tool rotation speed and welding speed 78, 120 mm/min.The characterization was carried out to understand the various zones created after the welding through microstructure analysis. The tensile test was carried out to study the effect of welding speed on tensile strength and the fracture behavior of the weld samples.The hardness profile measurement was carried out by Brinell hardness testing.

II. EXPERIMENTAL PROCEDURE

In this present research work the attempt was made to study the effect of welding speed on mechanical properties of friction stir welding of Al alloy. For this purpose the extrusion product of AA6101 T6 was utilized for the joining by friction stir welding. The T6 is the temper designation of the alloy indicating that the alloy was solution heat treated and artificially aged. The thickness of the plate utilized for FSW was 6mm. The FSW of AA 6101 T6 was carried out at metallurgical and materials Engineering Department of the Maharaja sayajirao university of Baroda, vadodara. The vertical milling machine was used for friction stir welding with tool tilt angle of 2 degree and 8 -10 KN load applied downward during tool traverse. The tool was made up of EN24 steel. The chemical composition of the AA 6101 T6 is indicated in the following table [1]. The chemical composition of the AA 6101 T6 was confirmed by the EDS (Energy Dispersive Spectroscopy).

Table 1 The chemical composition of AA 6101 T6 alloy

Elements	%
Al	Balance
Mg	0.6
Si	0.5
Zn	0.021
Cu	0.074
Cr	0.015
Zr	-

The two plates of AA 6101 T6 having dimensions of 100mm x 100mm x 6mm were butt welded by friction stir welding. The following fig 2 indicates the dimension of the weld sample.

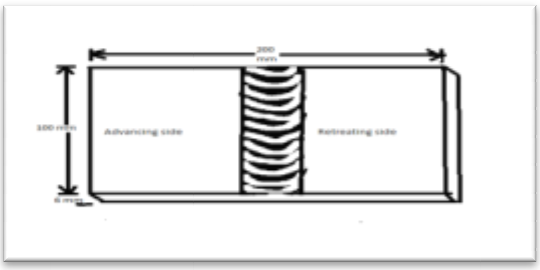

Figure 2 dimension of weld sample

For the present research work the following process parameters were selected . The friction stir welding was carried out with hexagonal pin with concave shoulder. The diameter of the shoulder and pin length was 20mm and 5.7mm respectively. The samples were welded at 1070 rpm tool rotation speed with two different welding speed i.e 78 and 120 mm/min.

After welding the microstructure analysis was carried out with help of Neophot 2 and SEM (scanning Electron Microscope) at 250X magnification. The etchant use for the development of microstructure was 4M keller. It was prepared by mixing of Hydrofluoric acid 6ml (HF), Hydrochloric acid 12ml(HCl), Nitric acid 22ml (HNO_3) and 60 ml distilled water. The immersion time for the eatching was 1 to 3min.[8]

The hardness profile measurement of friction stir welded sample was done across the each zone from Basemetal at Advancing side to Base metal at retreating side. The Brinell Hardness test was carried out using 2.5mm diameter of hardened steel ball indenter & 31.25 kg load. The following equation (1) was used to calculate the BHN theoretically.

$$\text{BHN} = \frac{2P}{\pi D(D - \sqrt{(D^2 - d^2)})} \quad \text{……….(1)}$$

Where, P = Applied load, kg, D = Diameter of indenter, mm, d = Diameter of indentation, mm

The tensile test was carried out as per ASTM E8 standard. The following fig. 3 indicating the dimension of the tensile specimen as per ASTM E8 standard.[9]

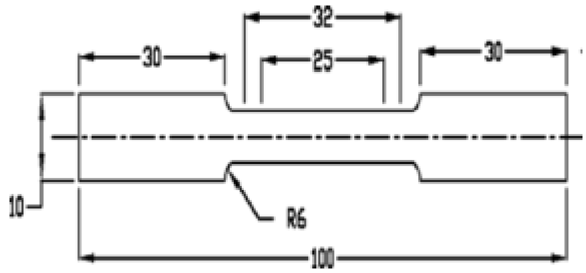

Figure 3 dimension of tensile test specimen as per the ASTM E8 standard

The fractrography of failed tensile sample was carried out at metallurgical and Materials Engineering department, The M.S.University of Baroda. The fractrography was conducted with help of Scanning Electron Microscope at different magnifications i.e 50x,100x 250x 500x and 1000x

III. RESULT AND DISCUSSION

The typical microstructure of as received conditions (base material) is shown in fig.4 The microstructure comprises of the coarse grains of aluminum with the hardening precipitates of Mg_2Si. From the microstructure analysis, there were different zones observed in the weld samples.

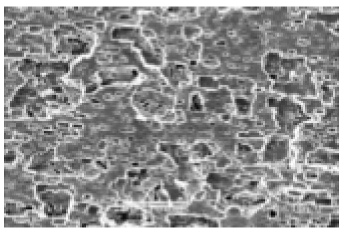

Figure 4 Microstructure of AA 6101 T6 alloy

The different zone observed are weld centre, Nugget zone, thermo mechanically affected zone, heat affected zone, and unaffected or base metal region as shown in following fig (5).

The formation of nugget region in the centre of the weld region is still unknown why it forms? But the lots of research work is going on to find out the origin of nugget region. The weld centre consist of extremely fine recrystalized grains of Al with the breaking of the coherent precipitates of Mg_2Si.The size of the precipitates are extremely finer compare to the other zone of the weld. The distribution of the precipitates is uniform throughout the weld centre region. There was sever plastic deformation was observed and the precipitates get destroyed and also some reprecipitation observed. There was also formation of some oxide layer form at either at the advancing side or at the retreating side of the weld sample forming some uneven boundary between the weld centre and the TMAZ and thus make some differentiation between them.

In the TMAZ, the microstructure consists of extremely fine grains of the Al with fine size of the precipitates of Mg_2Si. There are presences of more precipitates free zones compare to weld centre. At boundary near the TMAZ and weld centre, there is formation of an oxide layer. The formation of this oxide layer is also became the interesting part of the research why it was form? But from findings, it may be generated during the rotation of tool, metal gets oxidized.

The nugget region was observed near the bottom root portion of the weld centre region. The nugget region comprising of banded structure. It is also called as onion ring structure. The bands are distributed in such a way that there was formation of alternate bands of light and dark bands with different coherency and density difference of precipitates.

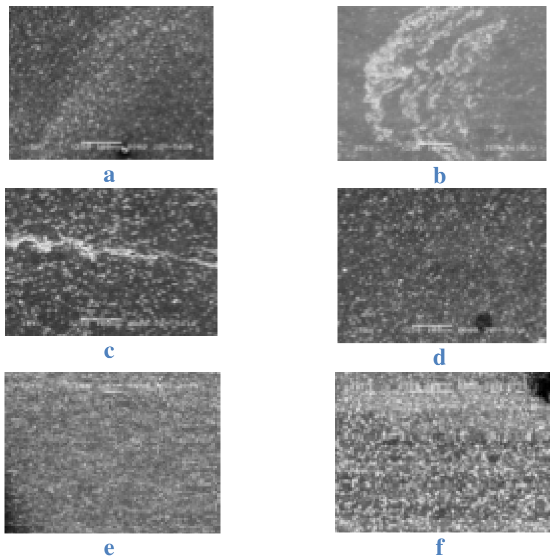

Figure 5 SEM micrographs of fsw sample at 250x magnification a.weld centre, bNuggaet c.TMAZ at RS, d.TMAZ at AS, e. HAZ at AS, f. HAZ at RS

The HAZ forms on the both the side of the weld.i.e.advancing and retreating side of weld. The reason behind formation of the heat affected zone is temperature difference across the weld. Because before the welding, the alloy plate was at room temperature. When the welding done by the rotation of tool there was substantial increase in temperature due to the friction generated between the tool and work piece and due to the plastic deformation of work piece. So, the grain growth was observed in the HAZ. The microstructure comprising of the coarse grains of aluminum with ripen precipitates of the Mg_2Si

The brinell hardness test result indicated there was an average 57 % decrease in the hardness of weld region compare to Base metal.

The tensile test result indicated that the weld prepared at 1070 rpm tool rotation speed at 78 and 120 mm/min welding speed posses the tensile strength of 108 with 11.32 %

elongation and 123 Mpa with 13.6 % elongation respectively. The failure analysis of the failed tensile test specimen indicated the mixed mode failure of ductile and brittle behavior. The following figure (6) indicates the fractrographs of failed tensile specimen which welded at 1070 rpm and 78 mm/min welding speed. The fracture surface indicated the mixed mode failure of ductile and brittle behavior.

The observation was carried out that there is a presence of some cleavage and steps. There is also presence of wide and long micro cracks The figure (7) indicates the fractrographs of the failed tensile specimen which was welded at 1070 rpm tool rotation speed and 120 mm/min welding speed. It also having the mixed mode fracture of ductile and brittle behavior. There is presence of elongated and equiaxed dimple structure with fine microcracks and voids are present.This reveal that there was no time for proper agglomeration of material.

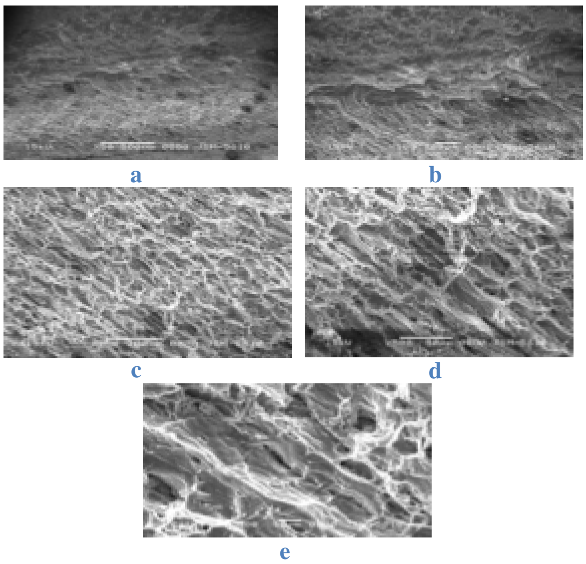

Figure 6 Fractrodraph of weld sample prepared at 1070 rpm tool rotation speed and 78 mm/min welding speed a. 50x b.100x c,250x, d. 500x, e. 1000x magnification

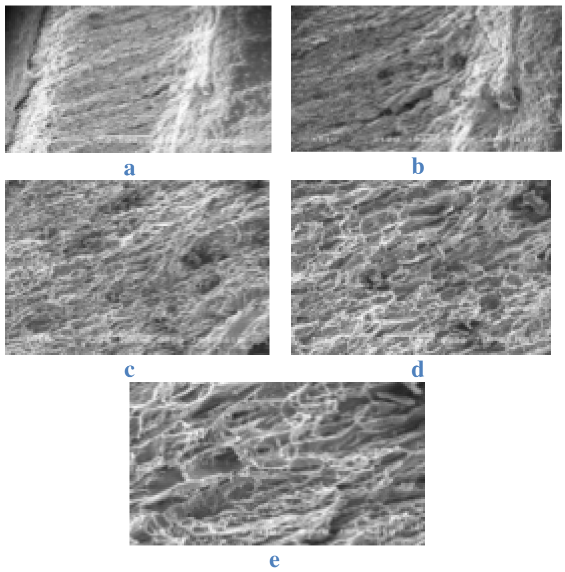

Figure 7 Fractrodraph of weld sample prepared at 1070 rpm tool rotation speed and 120 mm/min welding speed a. 50x b.100x c,250x, d. 500x, e. 1000x magnification

IV. CONCLUSIONS

1) The microstructure of weld comprise of the different zones namely, weld centre, TMA Z,HAZ on both side of the weld centre, i.e Advancing side and Retreating side. The each zone is having its own characteristics in terms of the grain structure and distribution of Mg_2Si precipitates. There was good transition observed from one zone to other.
2) The tensile test result indicating that with increase in welding speed there is increase in tensile strength of weldments but fracture surface reveal that there was present of some micro cracks and voids which is further indicating the improper agglomeration of weld.
3) The Hardness profile measurement indicating that there was an average 57% decrease in hardness compare to Base metal.

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